# A Map Enhancement for Terrain Visualization Under Night Vision Goggle Compatible Lighting Systems

by

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## ABSTRACT

For the Army aviator, Night Vision Goggle (NVG) flight in the tactical rotary-wing profile is a very demanding, task saturated environment. Map navigation is just one of the many tasks that must be accomplished during flight. The dim, monochromatic lighting required for NVG flight alters map colors, decreases image detail and map feature contrast, often making terrain feature recognition more difficult. A cartographic analysis and resulting map enhancement is needed to improve feature recognition, allowing easier navigation and safer flight. In this study, it was found that when applying a non-gray scale (magenta based) relief shading to a 1:50,000 scale military topographic line map, the surveyed aviators determined this shading improved or significantly improved their ability to visualize the terrain. It was also found that a medium level of shading (75% DEM opacity) was preferred.

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## INTRODUCTION

The objective of this research paper is to determine if a non-traditional method of relief shading can be used to treat a 1:50,000 scale military topographical line map (TLM) in a manner that allows the Army aviator to more easily "see" the terrain in "3-D" while viewing the map under Night Vision Goggle (NVG) compatible blue-green lighting. To better illustrate the need for such enhancement an illustrative vignette is provided.

The following is a typical scenario or "day in the life" of an Army helicopter pilot. This pilot has been deployed to an austere location for the last 45 days. The food is palatable, but there is little variation in menu. Opportunities for a shower and relaxation are few. As a member of the night crew, his official duty day goes from 1600 to 0400 hours (4pm to 4am). He tries to sleep on his cot during the day, but the heat, winds and activities of the day crews make quality rest difficult to obtain.

The missions are flown under total darkness, where even the best NVGs render a dark, monochromatic image of the low contrast terrain. As his UH-60 Blackhawk helicopter flies along at 150 miles per hour, a mere 75 feet above the ground en route to his target area, his cockpit (see **Figure 1**) is a picture of task saturation. In addition to duties as navigator and the requirement to maintain airspace surveillance for collision avoidance, the aviator frequently finds himself re-computing fuel consumption, writing down enemy intelligence report updates from one radio, listening to the supported ground

unit on another radio, and checking in with the flight operations center on yet a third radio. Sometimes all of this seems to happen simultaneously.

**Figure 1**. UH-60 (Blackhawk) Helicopter Cockpit. The pilot is wearing a liplight.

As the navigator, the aviator is required to give steering guidance to the pilot on the controls. He does this by viewing the terrain outside the aircraft through his NVGs, then looking at his map to find the aircraft position and to see what terrain he expects to encounter next. He will then look outside the aircraft again, giving steering commands to the pilot on the controls and describing terrain features for the pilot to key off of. This is a repetitive exercise that happens time and again throughout the mission. Each time the navigator looks at the map, he must create a "3-D" mental image of the terrain that he will match to the corresponding terrain he sees through his NVGs. The aviator must build this image under dark, blue-green lighting on a non-relief shaded map.

This paper examines a new method of relief shading the previously un-shaded 1:50,000 scale military TLM that takes advantage of the blue-green NVG compatible

lighting requirement. A method that allows the aviator to visualize the terrain on the map and more quickly return his attention outside the cockpit where he can scan for wires, enemy and other hazards will enhance the safe operation of the aircraft. Even a tenth of a second reduction in the time required to visualize the terrain and look back outside could be the difference between spotting a hazard and falling victim to it.

In a pre-survey, conducted as part of this research, Army rotary-wing (helicopter) aviators were asked a series of questions relating to the visual properties and qualities of the 1:50,000 scale TLM when viewed under blue-green, NVG compatible lighting. Almost all of the aviators felt it was difficult to "see" the terrain in the dim, monochromatic lighting environment. While not the sole cause of an accident, viewing a map under supplemental or Auxiliary Aviation Lighting Devices (AALDs), which provide a dim, mono-chromatic light source, can contribute to a more stressful cockpit.

In calendar year 1997 there were twelve Class A through Class C Army helicopter accidents with NVGs in use, in which the causes were attributed to crew coordination or attention errors (see **Appendix A** for accident data and accident class definitions). These accidents resulted in one dead and three disabled aviators. The damage costs to aircraft and equipment was $27,116,392. Injury costs amounted to $1,123,758. While it would be extremely difficult to determine exactly how much cockpit workload is attributable to navigation tasks, any decrease in the cockpit workload can improve crew coordination and could aid attention or fixation problems.

Army aviators are very competent at navigational tasks. During training flights, they continually seek to build and hone their navigation skills. But, regardless of their skill level, "map reading" still requires time to repeat each visualization iteration. This is

time that could be spent looking outside for obstacles or hazards. Additionally, factors like fatigue, the stress of a very "busy" cockpit or extended flight hours may increase the aviator's perceived workload and make routine tasks even more difficult and time consuming. Any method of decreasing the aviator's workload will correspondingly decrease the perceived stress of the cockpit environment and allow the aviator to be more productive and make better decisions.

The current generation of 1:50,000 scale military TLMs are a high quality product. However, any improvement that could lead to an increase in safety is one that should be investigated.

**Components of the NVG Cockpit**

There are three key components that interact in the NVG cockpit: the NVGs, the AALDs and the human eye. These components should be expanded upon before any of the research in this paper is discussed. This will greatly aid in the reader's understanding of this paper, as not all people are familiar with tactical aviation, especially that in the NVG realm.

The first component that makes low-level, low-illumination flight possible is the actual night vision device. In this case the most commonly used device is the AN/AVS-6 (see **Appendix B** for an AN/AVS-6 picture and sensitivity curve). This is a binocular, helmet mounted system that intensifies ambient lighting. This small photocathode device can intensify ambient light 2,000 to 3,500 times and provide visual acuity of 20/200 under ideal conditions. While the AN/AVS-6 is sensitive to light in the 540 to 820 nanometer (nm) range, its peak sensitivity is from 650 to 750 nm. This is the portion

of the visible spectrum that has the highest amount of reflected energy at night (TC 1-204 1988).

The next component is the Auxiliary Aviation Lighting Device (AALD). These devices are lightweight, miniature, self-contained light sources that the aviators use to illuminate maps, operational checklists, cockpit instruments and switches, and other items necessary for flight. The AALDs can be grouped into three categories: liplights, fingerlights, and flashlights with filters (see Appendix C for sample pictures).

There is some difference in the AALD's used in the NVG cockpit. These devices vary greatly in radiance (brightness compatibility with NVGs), chromaticity (measure of exact color of the filter), and luminous transmittance (measure of light that passes through the filter) (Fairneney and Tassinari 1996). Although a draft Statement of Need-Clothing and Individual Equipment was submitted by the U.S. Army Aviation School at Fort Rucker, AL, the definitive solution to obtaining a single, NVG compatible light source to meet the aviator's needs is still pending. Until a 100% compatible device is found and purchased in sufficient quantities to equip all aviation crewmembers, a variety of devices varying in NVG compatibility will continue to be used for NVG flight. It is specifically for this reason that the map treatment developed during this study was made to be effective when illuminated with the full range of available AALDs.

The liplight is composed of one to three light emitting diodes (LED) molded into plastic, that mount to the helmet microphone boom. The light is activated when the aviator applies pressure to a microswitch with his lip. These devices are usually powered by two AA batteries. The fingerlight most often consists of a single LED molded into plastic and attached to the index finger of the aviator. In order to keep the device as

small as possible, the finger light is most often powered by a small calculator type battery. Both the finger and lip lights are generally made with gallium phosphide or gallium arsenide LEDs that have peak emittance wavelengths of 565 and 600 nm (McGowin, et al. 1995). These lights would appear greenish-yellow to the viewer.

The flashlight filters are usually found in sizes to fit the standard Army flashlight (MX-991) and the AA Maglight$^{tm}$. The filters are made from plastic or single and dual laminated panes of glass, and may or may not have a dielectric coating to control output. While usually found in the blue to blue-green color spectrum, the exact color of light emitted seems to be as many as the number of manufacturers producing them. While there has not been an optimum device identified, it has not been for lack of testing. The United States Army Aeromedical Research Lab (USAARL) has tested many devices to determine their conformance to ANVIS radiance, chromaticity, and photopic transmittance requirements.

As noted above and shown in the diagram in **Appendix B**, the NVGs are highly sensitive to the red and near-infrared portion of the visible spectrum and much less sensitive to the blue and green portions of the visible spectrum. This gives aviators a portion of the visible spectrum that they can use to illuminate their cockpit and not interfere with the operation of their NVGs. If an aviator were to use a red lens flashlight, the NVGs would amplify that light 2,500 to 3,000 times and effectively blind the aviator. He would see nothing outside the cockpit window, much like taking a flash picture through a window. The aviator would only see a mirror image of himself. In addition to the spectral requirements, the lights must provide a usable amount of light, but not be too bright as to interfere with the operation of the NVGs. As there are no perfect filters, a

blue filter, for example, will still transmit some light energy in the green and red portion of the visible spectrum. As long as the intensity is not too high in the red wavelengths, the light will still be usable.

The last component of the NVG cockpit that is involved in this scenario is the human eye. The most common conditions for viewing maps are under white light conditions where the full spectrum of visible light is available for interaction. This is not the situation in the NVG cockpit. The NVG cockpit is dim enough so that the rods (night vision cells) are active, but not so dim that the cones (color/day vision cells) are unusable. The rods are most sensitive to 510 nm (green light) and the blue sensitive $\beta$ (beta) cones have their peak sensitivity in the 440 nm region (blue light) (Hunt 1987). The problem, though not usually perceived as a problem by the aviator, is that the cones do not usually become fully effective under this lighting. Additionally, the $\beta$ cones are found in about $1/20^{th}$ and $1/40^{th}$ the amount of the green sensitive $\gamma$ (gamma) and red sensitive $\rho$ (rho) cones (Hunt 1987). This is, to say the least, not the optimum map viewing environment.

## BACKGROUND

### Previous Work

There has been some work in the past with regard to enhancing the topographic map product through means of relief shading, layer tinting, contoured elevations and combinations of the three above methods. The various methods have been tested with regards to accessibility of information and visualization of terrain.

In one of the earlier studies published in *Perceptual and Motor Skills*, entitled "Some Effects of Layer Tinting of Maps", the two researchers tested 10 military officers

on the tasks of determining altitudes at selected grids and finding grid coordinates in the tinted and untinted portions of the test maps. The researchers found that when testing a group of military officers, layer tinting significantly reduced the time required to determine altitudes at specific locations on the maps, but significantly increased time required to determine grid coordinates when using the same map (Kempf and Poock 1969). The tests used 1:50,000 scale contoured maps. The colored layer tints progressed from greens (lower elevations) to yellows to browns to whites. No other form of map treatment was compared or contrasted.

In a study entitled "The Effect of Shaded Relief on Map Information Accessibility" the researcher found that "the use of shaded relief terrain symbology on a map to some degree impairs the ability of a map reader to extract non-terrain information" (Delucia 1972:17). The explanation for this was due to the fact that relief shading would "reduce the level of contrast with all the other map symbols which must be superimposed upon them" (Delucia 1972:17). While thought provoking and seemingly intuitive, the study did not focus on terrain visualization, which is the subject of interest in this paper.

In a later study, the above researcher teamed efforts with some of his colleagues in an endeavor entitled "Some Objective Tests of the Legibility of Relief Maps". In this study the researchers looked at four different types of relief maps (contours, contours with relief shading, layer tints and digital or spot heights) and provided performance rankings with respect to the tasks of: judging relative height, judging absolute height, visualizing the landscape, reading the map base. The results of this work showed that contours with relief shading were found to be second only to layer tinting in the map

reading task of visualizing the landscape (Phillips et al. 1975). An interesting note is that while confirming the fact that relief shading provides an immediate visual impact, it was noted that this is a technique that requires some experience to read well. This may well apply to Army aviators, a very experienced population of map readers.

In 1979 the U.S. Army Research Institute for the Behavioral and Social Sciences (ARI) commissioned a study entitled "An Approach to Assessment of Relief Formats for Hardcopy Topographic Maps". Their objective was to determine the merits of supplementing contour lines with other relief formats (Potash et al. 1979). Forty-eight officers and non-commissioned officers were assigned maps from one of three formats: contour lines, contour lines with layer tints, and contour lines plus shading. They were tested on eight types of problems: landform identification, ridge-valley identification, slope identification, identification of high-low areas on the map, spot elevation problems, vertical profile identification, terrain visualization, and defilade. Test results took into consideration both time required to answer the question and accuracy of the answers. The researchers found the addition of layer tints may enhance speed with which a map reader can extract some types of relief information, while the addition of shading does not decrease time required to extract information more than the addition of layer tints and may cause a decrease in performance where accuracy is concerned (Potash et al. 1979).

While previous studies demonstrate that there are differences between time required and accuracy of results when supplementing contour lines with other relief formats, the map scales, task conditions, and populations have varied. Drawing inference from these studies and applying the lessons learned to other populations would be difficult. It would be interesting to see the results of these studies if a population of

aviators (experienced map readers) were tested, and darkened conditions with only monochromatic (blue-green) lighting were used. Finally, a lot has changed since these studies in the areas of improved computing power, memory capacities, better graphic and image processing software and availability of cartographic data sets in digital format. Ideas and applications that were limited in the past may now be routine. Slight advantages provided by methods of relief enhancement which have been too arduous and time consuming to produce in the past may now be easily produced and applied to existing maps.

**Genesis of an Idea**

Since NVG flight created the requirement for a specific spectrum of supplemental lighting, aviators have experimented with using contrasting colors to highlight features of importance on their maps. A popular method of highlighting features such as wires or aviation routes is the standard pink highlighter marker (yellow highlighter markers are also used). This pink highlighter shows up extremely well when illuminated with blue-green lighting. Highlighters are also readily available, are easily removed with bleach, and do not opaque background features. All of these features make them a popular choice for some NVG aviators. The ability to draw attention to a feature without opaquing the background information is the thought behind the concept presented in this paper.

Relief shading of terrain is an accepted method of increasing the map reader's ability to perceive terrain relief. Traditionally, cartographers have used gray scale values to shade their maps. This method works well in most situations, but reading maps in a dimly lit cockpit, with only monochromatic (blue-green) light available is not a normal

situation. Additionally, gray relief shading remains a constant "darkness" when illuminated with white or monochromatic light. This holds true regardless of the lighting intensity. Dark relief shading may not be desirable when a using a dimmer, monochromatic lighting source.

## GOALS

The primary goal of this study was to determine if a relief shading enhancement of specified colors, other than standard gray-scale, when applied to the 1:50,000 scale TLM would allow the aviator, viewing the map under blue-green lighting, to better visualize the terrain than if viewing an untreated base map. Additional goals were to determine what level of shading would be preferred and if the relief shading was acceptable for daylight use. This shading needs to work well when illuminated by all of the currently used AALDs. With this in mind the survey results would be analyzed to see if aviators using one particular device found the treatment particularly effective or detrimental, or if they preferred one level of shading to another.

Restated, the hypothesis is:

1. Relief shading a 1:50,000 scale TLM will allow an Army rotary-wing aviator to better "see" or visualize the terrain in "3-D".
    a. This improvement will apply to the unshaded base map versus a series of shaded maps of that same area.
    b. The improvement will be effective when illuminated under the full spectrum of NVG compatible AALDs.
    c. The relief shading will be suited for day (white light) use.
2. The surveys will result in a general agreement of which level of shading (most likely the 75% opacity) will be most effective. There will most likely be a difference in shading preference between AALDs used.

# METHODS

## Operational Theory

Unlike the typical map reading situation, which usually consists of viewing a map product under white light, this monochromatic light environment has limitations, but also creates an advantage, which the cartographer can use.

In her thesis, Erikson (1991) performed many tests on the effect of non-white light sources on the visual characteristics of colored lines, as perceived by the map reader. Her work is similar in theory to this application of relief shading. Erikson explained the interaction of the colored ambient lighting and map colors when she wrote, "All colored light is lacking some portion of the visible color spectrum. This means that any surface whose reflectance spectrum includes none of the wavelengths present in the ambient light source will appear black to the observer. For instance, green objects appear black under red light. Objects reflecting the entire visible spectrum of the light source will appear white even though the light itself is seen as colored" (1991:2).

One of the illumination devices used in this study (WAMCO NV-4AMG, glass monolithic filter on standard Army issue flashlight, CIE '76 u'=.142, v'=.525, radius = .045, photopic transmittance Y% = 15.4 all for 2100K source) consists of approximately 60% blue light, 35% green light, and 5% red light. A color sample of a relief shaded area taken from an evaluation map by the Photoshop$^{tm}$ color picker (5x5 pixel sample size) revealed that the color of the shading is composed of 24.3% blue, 28% green and 47.7% red.

The composite diagram (**Figure 2**) illustrates the interaction of the blue-green lighting, the reflectance of the spectrum of the colored shading, and the retinal sensitivity of the eye as it occurs in the NVG cockpit. In the diagram, the blue-green light curve peaks in the blue portion of the visible spectrum and tapers towards the red portion. The shaded area, representing the blue and green portion of the relief shading color would, using Erikson's analogy, not be visible as its reflectance spectrum closely matches the spectral signature of the incident light. The red shaded portion of the shaded relief color would show up in a dark, shadow-like manner, as the blue-green light source contains little red light and would therefore be mostly absorbed. The small amount of reflected red light would be perceived, as the red cone is the numerically superior cone in the retina (Hunt 1987).

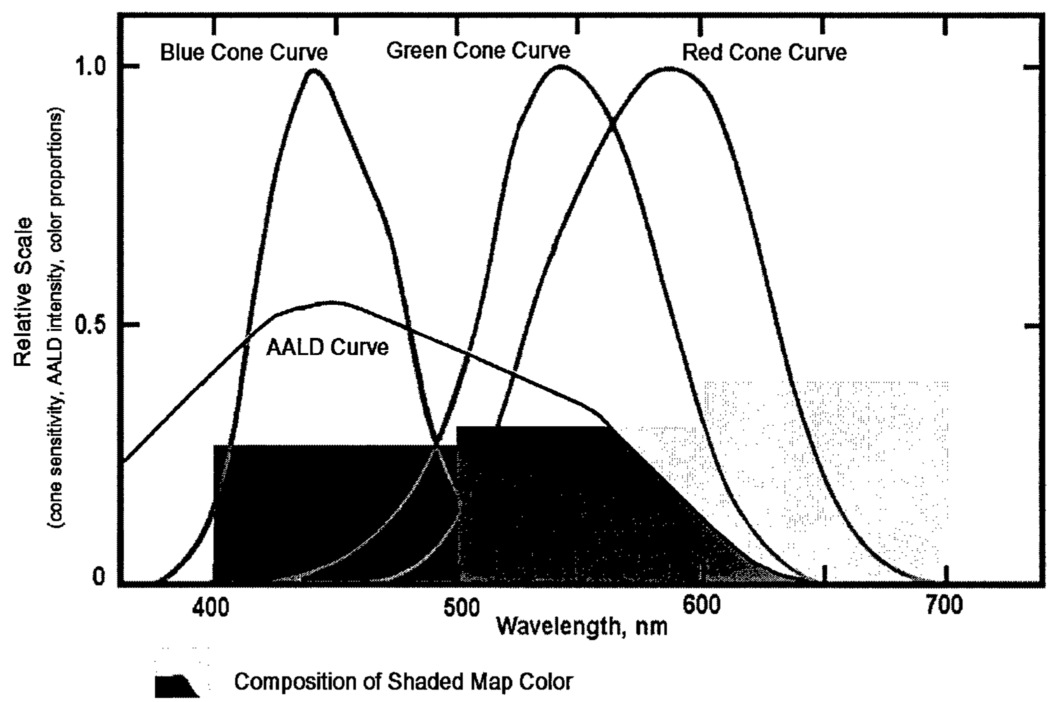


**Figure 2**. Composite depicting relative AALD intensity, cone receptor sensitivity and decimal equivalent by color of shaded map area.

The net result is terrain enhancing relief shading with little of the user information placed in the visual background. This is the desired effect. When illuminated with the full spectrum of light in white or day light all colors would reflect the incident light energy and be visible. This would provide effective shading for day use as well.

**Map Production**

The concept for this project was to create, from existing digital products, a relief shaded 1:50,000 scale military TLM. All work would be done on a medium performance (133mhz) personal computer using commercially available software. No special programs or hardware/devices would be required. This would ensure the simplicity and ease of replication of the project.

During the development of methodology and the corresponding map product, the following assumptions were made:

1. Relief shading is accepted as a map treatment that allows the viewer to better interpret the terrain relief or "see" the terrain in a 3 dimensional aspect.
2. Traditional relief shading techniques using 256 levels of gray tends to opaque background elements and could obscure items such as a pencil mark if on the shaded side of a hill. At the 1:50,000 scale the relief shading would be such that user information would be put in the visual background.

The first task was to choose test areas from which to create sample maps. The areas had to have significant terrain relief, had to be contained in 1:50,000 scale data on the National Imagery and Mapping Agency (NIMA) Compressed ARC Digital Raster Graphics (CADRG) CD-ROMs, and they had to have a corresponding 7.5 minute (30 meter) digital elevation model (DEM) available for free download from the United States Geologic Survey (USGS) file transfer protocol (FTP) internet site.

Two areas, although there were many possibilities, met the above requirements and were chosen. The first was the Stone City area on the southern Ft Carson, Colorado

military reservation. This area is characterized by rolling terrain, but with very noticeable relief. Additionally this area could be used as an actual in-flight test map by a surveyed aviation unit. The second area chosen was the Ammonia Tanks area in the Nevada Test Range. This terrain sits on the edge of a mesa whose erosion provides for a heavily contoured map surface. Many other areas would work well for this project, but the fact is, two areas had to be chosen and there were few pros or cons to be considered when choosing from the many available areas. One of the most desirable areas from the standpoint of flight testing, Ft Irwin, California (National Training Center), was not available in a 7.5 minute DEM.

With the test areas chosen, the 1:50,000 scale base maps were created from the CADRG using the NIMAMUSE 2.0 Raster Importer. The extents used to select these base maps were the same as the extents on the corresponding USGS DEM. This would minimize the need to shift and match layers once in Adobe Photoshop$^{tm}$. The created base maps were exported as red, green and blue (RGB) bitmap files.

The desired DEMs were located at the USGS FTP site and downloaded. An interesting challenge occurred here as few software products available for use on this project actually read the new Spatial Data Transfer Standard (SDTS) format. Fortunately, Dr. Peter Guth, United States Naval Academy, has written a freeware program called MicroDEM+ that reads "any likely DEM" and will import a SDTS DEM for export in a more familiar format.

Once the DEM was exported as a bitmap file, it was imported into IDRISI for Windows$^{tm}$ to create a shaded, stretched image. The sun azimuth for the shading was set at 270 degrees. The sun angle was set at 30 degrees. A one- percent saturation contrast

stretch was used to stretch the image and increase contrast between shaded and non-shaded areas. The resultant image was exported as an IDRISI .img file. This was renamed as a .raw file for import into Photoshop$^{tm}$.

In Photoshop$^{tm}$ a new image was created that was the same size as the DEM. The DEM, imported as a .raw file, was then put in its own layer. Before the base map could be brought in, it had to be resized by Photoshop$^{tm}$. This was due to the fact that the images exported out of NIMAMUSE were not to scale, but were approximately two times as large as they should have been. Once corrected, the bitmap base map was then brought into the image as its own layer as well. At this point the image was dimensionally too large to be of practical use. Therefore, a section of the map with significant relief for that area was chosen and each image was cropped down to approximately a 4.6 x 3.9-inch map image. This size proved to be useful in preparing the surveys as four maps (1 base map, 3 relief shaded maps) fit on one standard 8.5 x 11-inch sheet of paper.

Finally, came the creation of the non-gray relief shading to shade the base map. As a starting point, Pantone 203 was used, as it most resembled a pink highlighter. A screen, the same size and pixel count as the DEM image was created. The screen was then filled with the Pantone 203 from the "paint bucket". This resulted in a pink screen. In order to create "pink" relief shading with pink values similar to those in the in gray scale values, the pink screen had to be multiplied in an image calculation by the gray relief shading, which resulted in a new image with corresponding cyan, magenta, yellow, and black channels (see **Figure 3**).

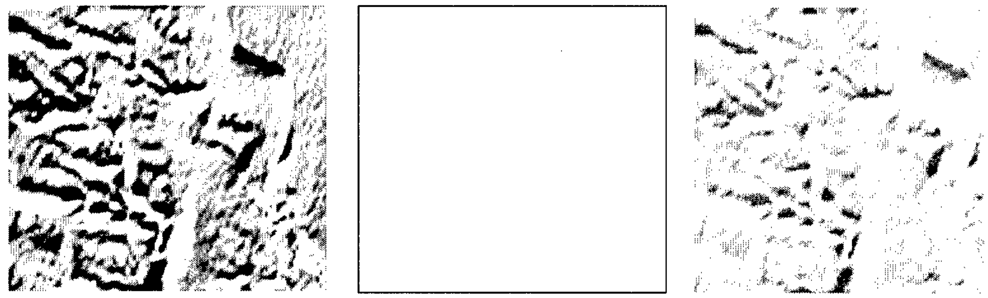

**Figure 3**. Standard Gray Relief Shading, Pink Screen, and “Pink” Relief Shading.

The following is an example of the image calculation operation:

| | | |
|---|---|---|
| Source 1 | pinkscreen.jpg | pinkscreen.jpg |
| Channel | Magenta | Yellow |
| Source 2 | graydem.jpg | graydem.jpg |
| Channel | Black | Black |
| Opacity | 80% | 80% |
| Result | pinkdem.psd | pinkdem.psd |
| Channel | Magenta | Yellow |

Initial pink relief shading was too saturated and too magenta looking. The entire base map was pink when the colored relief shading was overlaid. Two things were done to remedy this. First, more yellow was added to the pink screen. This made the resulting relief shading look a little more brown than pink, giving it a more natural, believable appearance. Next, adjustments were made to the image to increase the contrast between shaded and non-shaded areas. The saturation of the colors in the relief shading was also decreased. In order to do this, the saturation was decreased by 20% and the lightness was increased by 20%. Finally, the contrast was increased by 40% and the brightness increased by 25%. These final values were determined by a method of trial and error.

Many different combinations of magenta and yellow were tested before the final pink relief shading was created. Each iteration was tested by viewing the maps in a

totally darkened room and illuminating each map alternately with a three LED lip-light and then a standard issue Army flashlight that was fitted with a WAMCO NV-4AMG blue, glass filter. These AALDs represent two different colors of light and two different qualities of NVG compatibility. The final color combination decided upon was a mixture of 5% magenta and 15% yellow. This image was saved as a .psd file with the base map being the bottom layer and the pink relief shading being the top layer (**Figure 4**). The "multiply" blending mode was selected for the pink relief shading. This mode provided the best looking image. Photoshop$^{tm}$ Help describes the multiply blending mode as follows:

> "Multiply looks at the color information in each channel and multiplies the base color by the blend color. The result color is always a darker color. Multiplying any color with black produces black. Multiplying any color with white leaves the color unchanged. When you're painting with a color other than black or white, successive strokes with a painting tool produce progressively darker colors. The effect is similar to drawing on the image with multiple magic markers"

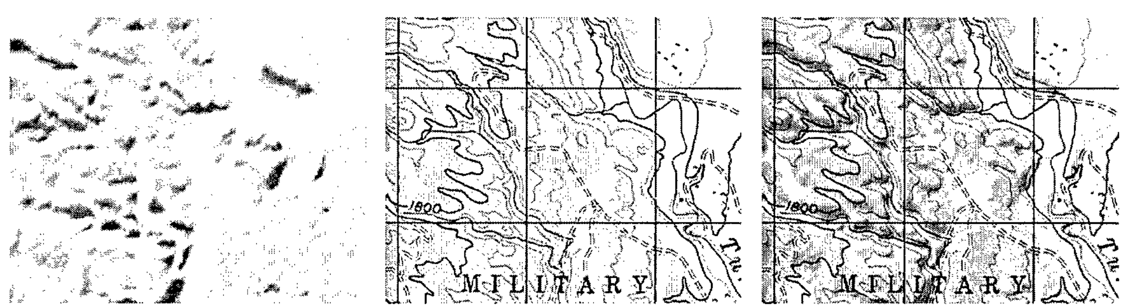


**Figure 4**. "Pink" Shading, Un-shaded Base Map, and Composite Shaded Map.

With the final map treatment completed, three different .jpg images were created for each map. One image was made with the pink relief shading at 50% opacity, the next with the pink relief shading at 75% opacity, and the last image was created with the pink relief shading at 100% opacity (see **Figure 5**).

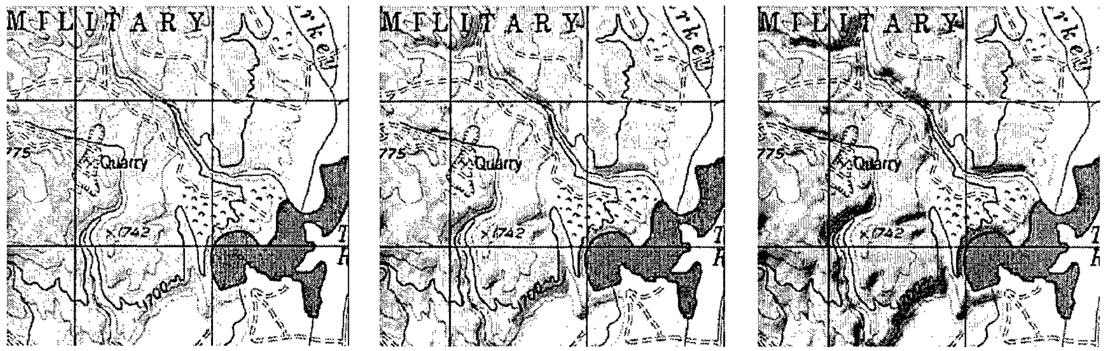


**Figure 5**. Shading at 50%, 75%, and 100% opacity.

These wide opacity brackets were chosen as 100% was the darkest opacity available and 50% opacity appeared to provide the minimal amount of usable shading. Narrowing the opacities below 100% and above 50% for an initial study would be very presumptive. However, using preliminary data from the results of this study, further bracketing for an optimum level of shading could be an objective of a future study.

Once the maps were completed they were mosaiced on one sheet; a base map with three shaded maps differing in opacities (see **Appendix D** for sample evaluation maps). The proofs were printed out on a Tektronix$^{tm}$ Color Laser printer. The proofs were copied on a Cannon$^{tm}$ Color Copier. Color copies, though not as high in quality as the color laser proofs, were used as they are approximately one-third the cost of a color laser print.

## Evaluation

The goal of the evaluation phase was to determine if the contour lines with relief shading treatment, as a method for enhancing the aviator's ability to visualize the terrain, was an improvement over the contour line-only base map. Additional information sought during the evaluation was which level of shading, light (50% layer opacity), medium

(75% layer opacity), or dark (100% layer opacity) the user preferred. The population for this survey consisted of volunteers from aircrews in available Army rotary-wing (helicopter) aviation units. The difficulty here is that since this is not an official Army study, no participants could be directed to participate. Only units that had no training conflicts and that would be willing to answer the evaluation surveys could be used. Major units that participated in this study were the Stetson Troop, 4th Squadron, 3rd Armored Cavalry Regiment (Ft Carson, Colorado), A Co. 2-501st Aviation Regiment (Fliegerhorst Kaserne, Germany), and C Co., 1st BN 160th Special Operations Aviation Regiment (Airborne) (Ft Campbell, Kentucky).

This is an almost ideal survey population from the point of visual homogeneity. As a group, Army aviators have been screened and have met strict requirements for color vision, depth perception, and visual acuity. These parameters are reverified on an annual basis during their annual flight physical. The group also has an aspect of being standardized in their training, both in flying and map reading/navigation skills. This standardization is often checked for verification throughout the Army's aviation units. This standardization of operating procedures and training would effectively eliminate a geographic difference in survey responses.

**Survey Process**

In the surveys, the participants were asked if they were better able to visualize (under NVG compatible lighting conditions) the terrain on the map product with the relief shading treatment or the un-shaded base map. They were then asked to rate the level of improvement, if any. Response choices ranged from Significantly Worse to

Significantly Improved. Suitability for daylight use and preferred level of shading were also queried (see **Appendix E** for a sample survey).

Each participant was given an evaluation folder with an instruction sheet, an answer sheet, and two sample maps. On each map sheet was an unshaded base map with three other shaded maps. Three different versions of the surveys were handed out. Version 1 had the opacities in order from 75%, 50%, and 100%. Version 2 had the opacities in order from 50%, 100%, and 75%. Version 3 had the opacities in order from 100%, 75%, and 50%. This was an attempt at a blind test so that participants would not always pick the middle choice because they assumed it would be the medium shading or likewise the last choice because it would be the darkest. Although, with casual examination, the differences were obvious, the shuffling of opacities was deemed a good idea.

The aviators were instructed to evaluate the map products in a darkened area, which closely matched the ambient lighting conditions of the NVG aircraft cockpit environment. They were also instructed to illuminate the maps with whatever AALD they normally used while flying with NVGs. Upon completion, the surveys were returned to the points of contact for the participating units and were mailed back.

Not all of the surveys that were handed out were returned. Of the 38 survey packets distributed, only 20 were returned. Additionally, Stetson 4/3 ACR was the only unit that received a class on color and night vision along with a personal explanation of survey procedures from the researcher himself. The other units took the surveys after being briefed by a single, local point-of-contact. This point-of-contact was, however, given instructions on how to administer the survey.

# DISCUSSION

## Evaluation Results

The survey results showed that participating aviators favored the relief shading treatment as a method of enhancing their ability to visualize terrain on a 1:50,000 scale TLM. Of the surveys returned, ten out of twenty found the treatment for the Stone City map a “Significant Improvement”. Nine out of twenty found the treated map of Stone City to be “Improved” over the base map. There was only one survey returned that found the treatment “Worse”. None of the returned surveys gave a “No Improvement” or “Significantly Worse” response for the map treatment. In the case of the Ammonia Tanks map, seven out of twenty found the treatment to be a “Significant Improvement”. Twelve out of twenty found the treated map of Ammonia Tanks to be “Improved” over the base map. There again was one survey returned that found the treatment to be “Worse”. None of the returned surveys gave a “No Improvement” or “Significantly Worse” response for the map treatment. **Table 1** shows the combined results for both maps. Additionally, the surveys overwhelmingly determined the relief shaded maps were suitable for day use.

**Table 1**. Survey Results (improvement)

| | Significant Improvement | Improved | No Improvement | Worse | Significantly Worse |
|---|---|---|---|---|---|
| Stone City | 10 | 9 | 0 | 1 | 0 |
| Ammonia Tanks | 7 | 12 | 0 | 1 | 0 |

A general preference for the level of shading also seemed to be apparent. Responses generally appeared to favor the 75% or medium shading for both the Stone City and Ammonia Tanks map areas. For the Stone City map, two of twenty participants

preferred the 50% level of shading, nine of twenty preferred the 75% shading, and seven of twenty preferred the 100% shading (one respondent made no choice). For the Ammonia Tanks map, five of twenty preferred the 50% level of shading, nine of twenty preferred the 75% level of shading, and five of twenty preferred the 100% level of shading (one respondent made no choice, one other chose both 50 and 75%). **Table 2** shows the combined results for both maps.

An initial hypothesized result of the shading preference was that aviators using the "dimmer" lighting devices such as the single LED lip-light would prefer a lighter level of shading and that those using a brighter lighting device such as the Army flashlight with blue filter would prefer a darker level of shading. The results actually showed that mean lip-light preference was 78.4%, while those using the Army flashlight with blue lens had a mean preference of 82.5%. Although this fits the initial hypothesis, the difference does not appear to be significant. A full table of survey results can be found in **Appendix F**.

**Table 2**. Survey Results (level of shading preference)

| | 100% | 75% | 50% |
|---|---|---|---|
| Stone City | 7 | 9 | 2 |
| Ammonia Tanks | 5 | 9 | 5 |

**Future Evaluations**

Ideally, this research would have been conducted as an official study having the backing and support of the U.S. Army and the U.S. Army Aviation Center, Ft Rucker, Alabama. This would have accomplished a few key items and allowed for a higher caliber of study. First, an aviation unit or units could be tasked to provide aviators for the evaluation. This would help ensure that a higher ratio of surveys handed out would be

returned. Additionally, a mix of aviators by type aircraft (aero-scout, utility, and attack) could be specified as participants. This would eliminate any bias based on the physical differences in cockpit lighting of each specific airframe.

The quality of maps could be improved and better testing conditions set. With a little bit of funding all participants could be given color laser ($1^{st}$ generation) maps. These maps are much better quality than color copies and would appear much closer to the quality of the actual 1:50,000 scale TLM. While the quality of the copy doesn't seem to be crucial to the evaluation process, it more closely replicates reality. For standardization each survey participant could use the same lighting device. Though not the device that the aviator prefers, this would help eliminate any skewing of the results based on chromaticity or luminance of the lighting source. Finally, a set of maps for a local flying area could be made and pilots could actually go out and fly the terrain using the treated and untreated maps. This would provide a better environment for the evaluation of a product that they might actually use and could lend it to in-flight testing scenarios. Tests such as navigational routes for time and accuracy, distance estimation, and landform identification could be coupled with eye movement sensors. These sensors have been used many times in the past by USAARL and could prove helpful in detecting fixation and effects of cockpit workload.

# CONCLUSION

## Implementation

The results of this study may prompt those concerned with aviation safety to further explore the possibilities of enhancing the readability of contemporary tactical map products or even explore the feasibility of implementing the colored relief shading treatment examined in this paper. Some inertia to implementation would lie in the expense and logistics of printing and distributing new maps to aviation units. The cost of reprinting maps, especially with a large supply of existing maps on hand, must always be weighed against the perceived benefits to aviation safety. It is for this reason that the shading, from the onset, was viewed as an enhancement that could be easily overlaid onto existing maps in much the same manner as range fans, air corridors, and flight hazards are added to make "Aviation Special" maps. In this manner, the shading could be applied using existing technology and practices, with no requirement to produce an entirely new set of maps. Additionally, the shading could be cut out of ranges, Special Use Airspace, and no-fly or garrison areas to increase contrast and to highlight these areas.

A note of interest is that the ground forces are or have switched to blue-green interior lighting in their vehicles. This method of shading, or other enhancements, could find application in the realm of the ground TLM user as well.

## Final Note

This is by no means intended to be a definitive solution to the problem of terrain visualization on TLMs. It is more the hope that this study could raise the consciousness of an often-ignored issue and prompt some work in that area. The non-gray, relief-

shading method presented in this paper is merely an exploration into a cartographic solution for a unique application. The adaptation of other methods should also be explored. As noted in the work of Kempf and Poock, DeLucia and Potash et al., and Phillips et al., such means as layer-tinting with supplemental contours or tinting with relief shading are proven effective methods of enhancing map products. Many years have elapsed since these studies and maybe the subject should be re-examined, especially now, with the requirement for a non-white light environment. Though often seen as a disadvantage, monochromatic lighting may offer the opportunity to apply traditional cartographic methods in ways not previously explored.

Finally, a revisit of the traditional ideas of cartography combined with modern computing capabilities and the need for a unique application may be the answer to the question someone is looking for. This question is not a matter of convenience to the Army aviator. It is more likely a question of life or death.

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# Appendix A

## Army Rotary Wing Accident Data

**Total Army Class A-C Accidents with NVG/S in Use with Crew Coord or Attention Errors**

| | A | B | C | FATAL | DISAB | DAMAGE ($) | INJURY($) | TOTCOST |
|---|---|---|---|---|---|---|---|---|
| **AH64** | 2 | 0 | 1 | 0 | 0 | $ 17,707,430 | $ - | $ 17,707,430 |
| **CH47** | 0 | 0 | 1 | 0 | 0 | $ 152,580 | $ - | $ 152,580 |
| **MH47** | 0 | 1 | 2 | 0 | 1 | $ 710,351 | $ 19,572 | $ 729,923 |
| **OH58** | 1 | 1 | 0 | 1 | 1 | $ 7,000,258 | $ 1,104,066 | $ 8,104,324 |
| **UH60** | 1 | 0 | 2 | 0 | 1 | $ 1,545,773 | $ 120 | $ 1,545,893 |
| **OTHER** | 0 | 0 | 0 | 0 | 0 | $ - | $ - | $ - |
| **TOTAL** | 4 | 2 | 6 | 1 | 3 | $ 27,116,392 | $ 1,123,758 | $ 28,240,150 |
| | | | | | | **COUNT OF AIRCRAFT** | | 12 |
| | | | | | | **COUNT OF ACCIDENTS** | | 12 |

Accident Data for Calendar Year 1997. Source: U.S. Army Safety Center, Ft. Rucker, AL.

## Army Accident Class Definitions

Class A is an Army accident resulting in:

a. Total costs of $1,000,000 or more and/or;
b. Destruction of an Army aircraft, missile or spacecraft and/or;
c. Fatality or permanent total disability.

Class B is an Army accident resulting in:

a. Total costs of $200,000 or more, but less than $1,000,000 and/or;
b. Permanent partial disability and/or;
c. Hospitalization of five or more people as inpatients.

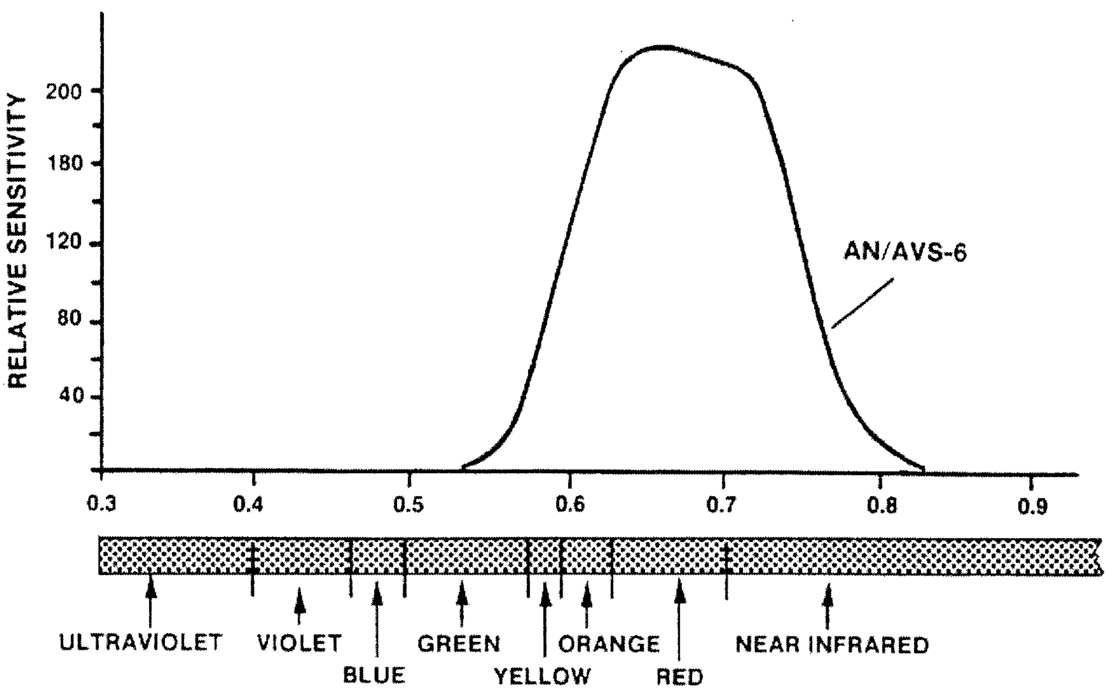
Class C is an Army accident resulting in:

a. Total costs of $10,000 or more, but less than $200,000 and/or;
b. Non-fatal injury resulting in loss of time from work beyond day/shift when injury occurred and/or;
c. Non-fatal illness/disability causes loss of time from work.

# Appendix B

## AN/AVS-6

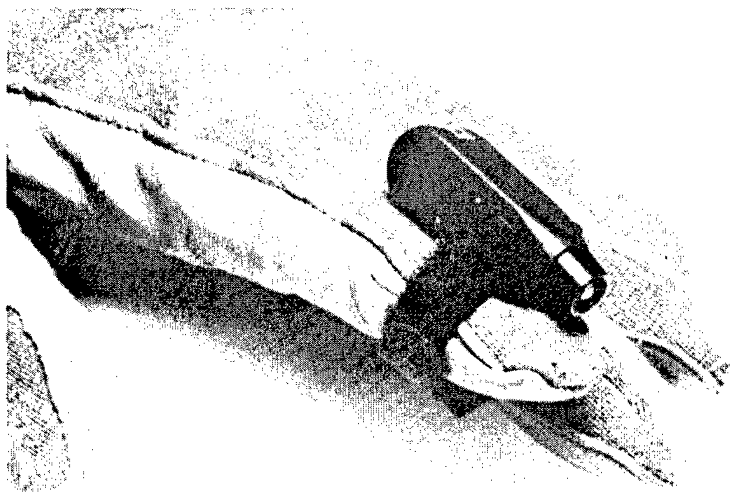
SPH-4 Flight helmet with AN/AVS-6 Night Vision Goggles. Source: TC 1-204 1988.



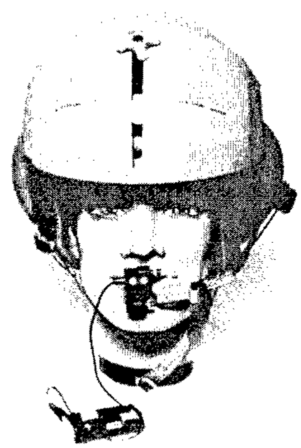

AN/AVS-6 Sensitivity Curve. Source: TC 1-204 1988.

# Appendix C

## Auxiliary Aviation Lighting Devices



Finger light. Source: McGowin, et al. 1995.

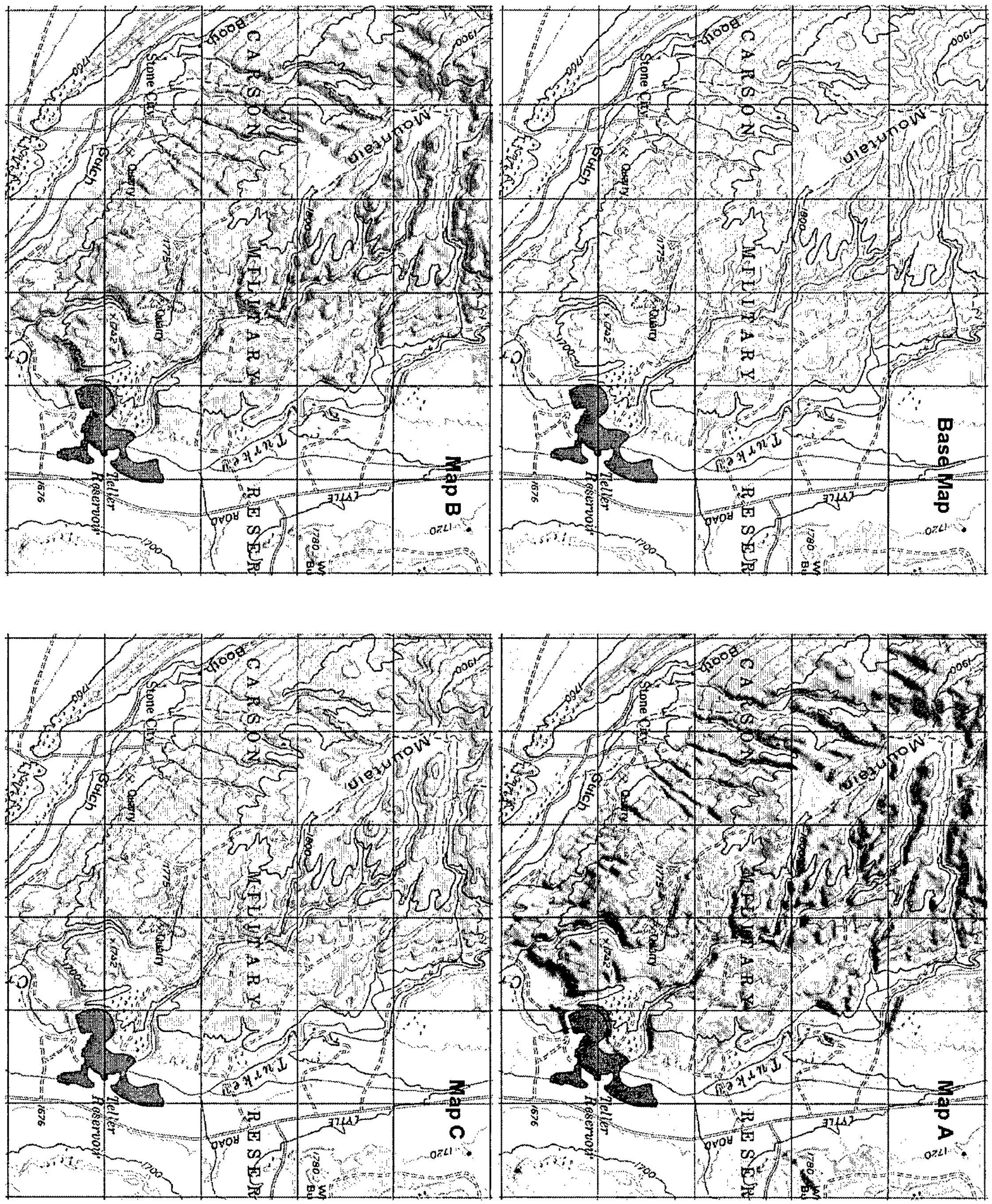


Lip light. Source: McGowin, et al. 1995.

# Appendix D

## Survey Map Examples

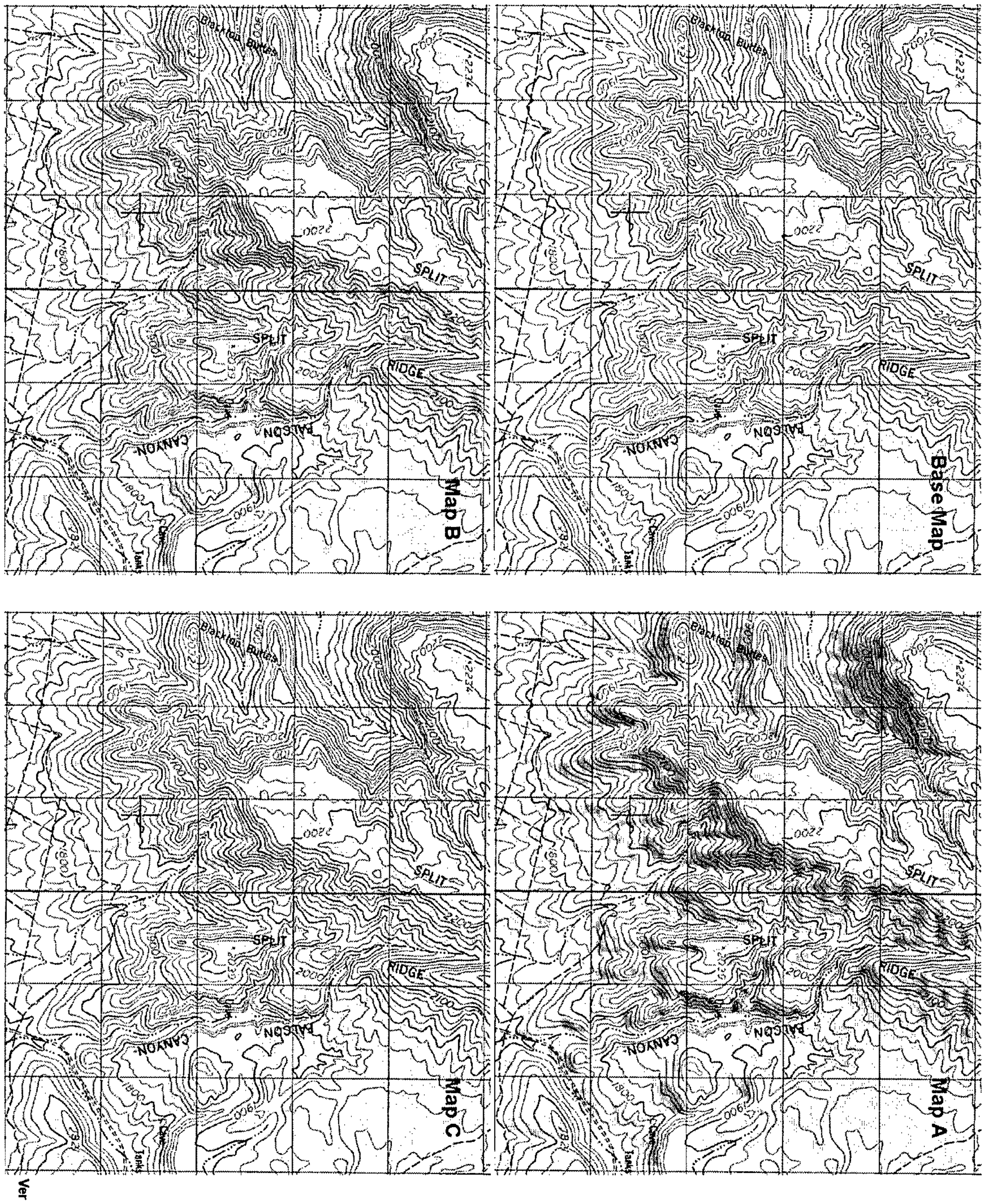
**Stone City**




Ver 3

Stone City Survey Map (Version 3).
Not to scale, reduced for display.

**Ammonia Tanks**




Ammonia Tanks Survey Map (Version 3).
Not to scale, reduced for display.

Appendix E

Survey Questionnaire

## Map Treatment Questionnaire

Relief shading of a map is intended to help the map reader visualize the terrain. This survey is being used to determine the most effective level of map shading when viewed under Night Vision Goggle (NVG) compatible lighting.

There are two enclosed mapsheets, each of a different geographical area. Each mapsheet has three different levels of shading for each map area. In a darkened environment, view each map area with your NVG compatible lighting device (lip-light, Army flashlight, etc.) and decide which level of shading you prefer.

Use the mapsheets to answer the questions on the attached questionnaire. When you are done with the questionnaire please return it to your POC.

Thank you for your participation in this survey.

Ver 3

1. Referring to the Stone City mapsheet, which shaded map A, B, or C, best helps you visualize the terrain? (Circle one choice)

A B C

2. Is the map also well suited for day use?

3. How would your rate the improvement over the unshaded base map? (Circle one choice)

| | | | | |
|---|---|---|---|---|
| **Significantly** Worse | **Worse** | **No Improvement** | **Improved** | **Significantly** Improved |

4. Referring to the Ammonia Tanks mapsheet, which shaded map A, B, or C, best helps you visualize the terrain? (Circle one choice)

A B C

5. Is the map also well suited for day use?

6. How would your rate the improvement over the unshaded base map? (Circle one choice)

| | | | | |
|---|---|---|---|---|
| **Significantly** Worse | **Worse** | **No Improvement** | **Improved** | **Significantly** Improved |

7. What type of lighting device did you use to evaluate the maps (3 LED lip-light from the Hangar, finger-light, Army flashlight w/blue glass filter)? Be as specific as possible.

Please add any comments regarding the maps and/or suggestions for improvements.

# Appendix F

## Table of Survey Results

Results by AALD type for the Stone City Map set

| Stone City | | | | |
|---|---|---|---|---|
| | | | | |
| **Device** | **Shading Pref** | **Improvement** | **Ver** | **ID** |
| 3 LED liplight | 50 | 5 | 3 | S1 |
| 3 LED liplight | 100 | 5 | 1 | S2 |
| 3 LED liplight | 100 | 5 | 1 | S4 |
| 3 LED liplight | 75 | 4 | 2 | S5 |
| 3 LED liplight | 75 | 4 | 3 | R2 |
| 3 LED liplight | 75 | 4 | 1 | G1 |
| 3 LED liplight | 75 | 4 | 3 | G3 |
| 3 LED liplight | 100 | 4 | 2 | G4 |
| 3 LED liplight | 75 | 4 | 1 | G5 |
| 3 LED liplight | 100 | 5 | 2 | G6 |
| 3 LED liplight | 100 | 5 | 2 | G7 |
| | | | | |
| 1 LED liplight | 50-75 | 5 | 2 | S3 |
| | | | | |
| | | | | |
| AAmag w/ blue-green glass filter | 75 | 5 | 3 | TF1 |
| Liplight AAmag with blue glass filter | 75 | 5 | 3 | TF2 |
| | | | | |
| | | | | |
| | | | | |
| Army Flashlight w/blue filter | 75 | 5 | 3 | TF3 |
| Army Flashlight w/blue filter | 100 | 4 | 3 | R2 |
| Army Flashlight w/blue filter | 50 | 4 | 3 | R3 |
| Army Flashlight w/blue filter | 75 | 4 | 3 | R4 |
| Army Flashlight w/blue filter | -- | 2 | 3 | R5 |
| Army Flashlight w/blue filter | 100 | 5 | 2 | G2 |

Results by AALD type for the Ammonia Tanks Map set

| **Ammonia Tanks** | | | | |
|---|---|---|---|---|
| | | | | |
| **Device** | **Shading Pref** | **Improvement** | **Ver** | **ID** |
| 3 LED liplight | 50 | 4 | 3 | S1 |
| 3 LED liplight | 75 | 5 | 1 | S2 |
| 3 LED liplight | 50 | 5 | 1 | S4 |
| 3 LED liplight | 50 | 4 | 2 | S5 |
| 3 LED liplight | 75 | 4 | 3 | R1 |
| 3 LED liplight | 75 | 4 | 1 | G1 |
| 3 LED liplight | 75 | 4 | 3 | G3 |
| 3 LED liplight | 100 | 4 | 2 | G4 |
| 3 LED liplight | 50 | 4 | 1 | G5 |
| 3 LED liplight | 100 | 4 | 2 | G6 |
| 3 LED liplight | 100 | 5 | 2 | G7 |
| | | | | |
| 1 LED liplight | 50 | 5 | 2 | S3 |
| | | | | |
| | | | | |
| AAmag w/ blue-green glass filter | 75 | 5 | 3 | TF1 |
| Liplight AAmag with blue glass filter | 75 | 5 | 3 | TF2 |
| | | | | |
| | | | | |
| | | | | |
| Army Flashlight w/blue filter | 75 | 5 | 3 | TF3 |
| Army Flashlight w/blue filter | 100 | 4 | 3 | R2 |
| Army Flashlight w/blue filter | 100 | 4 | 3 | R3 |
| Army Flashlight w/blue filter | 75 | 4 | 3 | R4 |
| Army Flashlight w/blue filter | -- | 2 | 3 | R5 |
| Army Flashlight w/blue filter | 75 | 4 | 2 | G2 |